

# **Reproductive Biology and Demographics of Endangered Lost River and Shortnose Suckers in Upper Klamath Lake, Oregon**

By

David L. Perkins\*<sup>1</sup> and G. Gary Scopettone

*U. S. Geological Survey, Biological Resources Division,  
Western Fisheries Science Center, Reno Field Station  
1340 Financial Blvd., Suite 161, Reno, NV 89502*

Mark Buettner

*U.S. Bureau of Reclamation  
Klamath Basin Area Office  
6600 Washburn Way  
Klamath Falls, OR 97603*

Report to the Bureau of Reclamation  
October 2000

\*Corresponding author: David\_Perkins@fws.gov

<sup>1</sup>Present address: U.S. Fish and Wildlife Service, 300 Westgate Center Dr.,  
Hadley, MA 01035

## CONTENTS

Abstract .....	4
Introduction .....	5
Study Sites .....	5
Methods .....	8
Results and Discussion .....	11
Timing of Migration and Spawning .....	11
Migration Cues .....	14
Spawning Behavior .....	18
Length of Time Individuals Occupy Spawning Areas .....	20
Size and Age at Maturity .....	20
Fecundity .....	21
Iteroparity .....	24
Fish Condition .....	24
Lakewide Distribution of Adults During Spawning Season .....	26
Demographics-Williamson-Sprague River System .....	29
Demographics-Springs .....	29
Relative Abundance .....	30
Discreet Stocks within Upper Klamath Lake .....	33
Management Considerations .....	33
Acknowledgments .....	34
References .....	35
Appendix A –Suckers captured from shoreline springs of Upper Klamath Lake .....	39
Appendix B – Fecundity of Lost River and shortnose suckers .....	40

## FIGURES

1. Map of Upper Klamath Lake, Oregon. ....	6
2. The abundance and mean catch per unit effort of suckers in the Williamson and Sprague rivers. ....	13
3. Proportion of male shortnose suckers captured in the lower Williamson River that released milt. ....	15
4. Temporal pattern of the size of Lost River suckers captured in the lower Williamson River and at shoreline springs. ....	16
5. Diel pattern of fish capture in the Williamson River. ....	17
6. Mean daily water temperature and discharge in the Williamson River. ....	19
7. Size distribution and sex ratio of Lost River suckers in the Williamson and Sprague rivers. ....	22
8. Size distribution and sex ratio of shortnose suckers in the Williamson and Sprague rivers. ....	23
9. Fecundity of Lost River and shortnose suckers. ....	25
10. Length-weight relationship of suckers. ....	28

11.	Size distribution and sex ratio of Lost River suckers captured at shoreline springs. ....	31
12.	Size distribution and sex ratio of shortnose suckers captured at shoreline springs. ....	32

## **TABLES**

1.	Prevalence of afflictions for suckers from the Williamson River. ....	27
A.	Number of suckers captured from shoreline springs. ....	39
B.	Fecundity of suckers. ....	40

## Abstract

We analyzed the reproductive biology and demographics of the Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris*, two endangered species endemic to the upper Klamath Basin of Oregon and California, from 1984-1997. Lost River suckers had distinct river and lake shoreline spawning stocks, and individuals of both species commonly spawned in consecutive years. In the Williamson River and lower Sprague River, spawning migration by both species occurred mainly during a 5-week period that started within the first three weeks of April and peaked between mid April and early May, although a separate, earlier (mid March) run of Lost River suckers may also spawn in the upper Sprague River. Migration of both species was several times higher at dawn (0500-0730 h) and evening (1800-2200 h) than other times of the day. Peak migrations almost always corresponded to peaks in water temperature, usually at 10-15°C. Lost River suckers were captured at springs along the east shore of the lake from late February through mid May, with peak spawning usually in mid March to mid April. Shortnose suckers were generally captured at the springs from late March through late May, but the time of peak spawning was not determined. Size and age at maturity was determined by recruitment from a strong year class (1991). Male Lost River suckers began recruitment into the adult population at age 4+ (375-475 mm). Substantial recruitment of females did not begin until age 7+ (510-560 mm). Male and female shortnose suckers began recruitment at age 4+, with the majority of fish recruited by age 5+. Males recruited at 270-370 mm; females recruited at 325-425 mm. Fecundity estimates were quite variable ranging from 44,000-236,000 eggs per female Lost River sucker and 18,000-72,000 eggs per female shortnose sucker. In 1984 and 1985, the spawning populations of both species were dominated by large, old individuals, with little indication of recent adult recruitment. In the next 13 years, only one strong year class (1991) recruited into the spawning populations of both species. This year class temporarily boosted population numbers, but annual fish kills from 1995 to 1997 eliminated most adults of both species. Associated with poor water quality caused by the proliferation and decay of blue-green algae *Aphanizomenon flos-aquae*, these fish kills raise concern that alterations to the lake ecosystem over the past several decades have

increased the magnitude and frequency of poor water quality. As a result, mortality rates of all life stages may have increased, thereby disrupting the species' life history pattern and potentially decreasing long-term population viability.

## Introduction

The Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris* are large, long-lived suckers endemic to the upper Klamath Basin of Oregon and California. Both species are typically lake dwelling but migrate to tributaries or shoreline springs to spawn (Moyle 1976, Scoppettone and Vinyard 1991). Once extremely abundant (Cope 1884, Gilbert 1898), both species have experienced severe population declines and were federally listed as endangered in 1988 (USFWS 1988). Much of the original habitat of these suckers has been destroyed or altered by conversion of lake areas to agriculture, dams, instream flow diversions, and water quality problems associated with timber harvest, loss of riparian vegetation, livestock grazing, and agricultural practices (USFWS 1988).

Knowledge of the life history of Lost River and shortnose suckers is fundamental to recovery of these species. The objective of this report was to present the results of studies conducted from 1987-1998 on the reproductive biology and demographics of Lost River and shortnose suckers, and to compare these results with earlier unpublished data.

## Study Sites

Studies were conducted on Upper Klamath Lake and the lower Williamson-Sprague river system (Figure 1). These waters form the upper portion of the Klamath River Basin in south-central Oregon and represent most remaining native habitat of Lost River and shortnose suckers. Upper Klamath Lake is a remnant of pluvial Lake Modoc that included eight major basins and encompassed 2,839 km<sup>2</sup> (Dicken 1980). Today, Upper Klamath Lake serves as a storage reservoir that provides water for agricultural irrigation, waterfowl refuges, instream flow requirements of anadromous fish, and hydroelectric power generation. At full capacity, the lake covers approximately 360 km<sup>2</sup> and has an average depth of 2.4 m. Most deeper water (3-12 m) is restricted to narrow trenches along the western shore. Lake elevation is controlled at the outlet by Link River

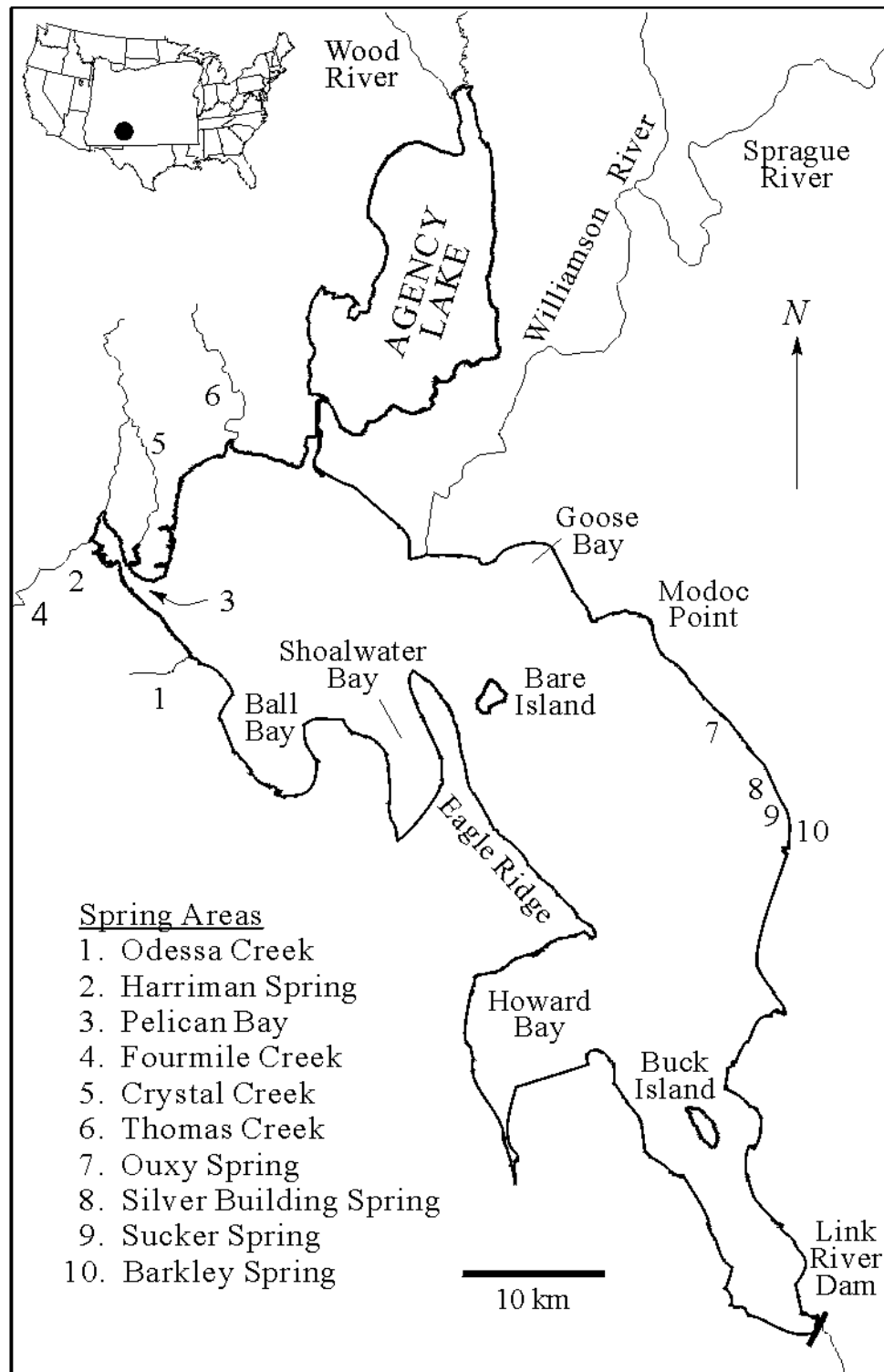


Figure 1. Map of Upper Klamath Lake, Oregon.

Dam and ranges from 1261 to 1263 m above sea level. Since the dam's completion in 1921, the lake level can be dropped up to 1.2 m lower than the pre-dam level, which reduces lake volume by more than 50%.

Upper Klamath Lake appears to have been eutrophic since at least the mid-1800s, but ecosystem changes during the past century, such as losses of riparian, wetland and lacustrine habitat, as well as increased nutrient input, may have contributed to the current hypereutrophic status (Miller and Tash 1967, Vincent 1968, Bortleson and Fretwell 1993, Kann 1998). These ecosystem disruptions are a likely cause of the shift in the phytoplankton community to the blue-green alga *Aphanizomenon flos-aquae*, which has produced nuisance blooms during summer and fall for at least the past 40 years (Miller and Tash 1967, Kann 1998, Perkins et al. 2000). The growth and decomposition of dense algal blooms in the lake frequently cause extreme water quality conditions each summer characterized by high pH (9-10.5), widely variable dissolved oxygen (anoxic to supersaturated), and high ammonia ( $>0.5$  mg/ L un-ionized; Wood et al. 1996, Kann 1998, Perkins et al. 2000). The degraded water quality that results from the algal blooms poses a significant threat to the endangered suckers because of frequent summer fish kills and reduced fitness and survival as a result of chronic stress (Perkins et al. 2000).

The Williamson-Sprague river system accounts for about 50% of the water input to Upper Klamath Lake (Hubbard 1970) and is considered the primary spawning area for Lost River and shortnose suckers. The Williamson River flows out of Upper Klamath Marsh 56 river kilometers (rkm) upstream from Upper Klamath Lake; springtime flow is usually about  $50 \text{ m}^3/\text{s}$ , but can exceed  $200 \text{ m}^3/\text{s}$ . The two main tributaries of the Williamson River are Spring Creek and the Sprague River. Spring Creek originates from cold springs ( $4.4\text{-}7.2^\circ\text{C}$ ) and reduces the springtime temperature of the Williamson River from its confluence at rkm 26 downstream to the confluence of the warmer Sprague River ( $8\text{-}17^\circ\text{C}$ ) at rkm 17.6. Lost River and shortnose suckers apparently do not spawn in the Williamson River above rkm 17.6, presumably because the water temperature is below their preferred range. From the Sprague River Dam at rkm 1.4 downstream to rkm 11.4 of the Williamson River (i.e., the area electrofished; see below), the river is 30-60 m wide and generally consists of riffles and glides 0.5-2 m deep, interspersed with several pools 3-5 m deep. In the lower 1 km of the Williamson River, where stock assessment

occurred, the river is 100-120 m wide and 3-5 m deep, with slow water velocity ( $<0.5$  m/s) and a muddy bottom.

A number of springs exist along the shoreline of Upper Klamath Lake, some of which are used as spawning areas by Lost River and shortnose suckers. We studied sucker spawning at a group of three springs (Sucker, Silver Building, and Ouxy) located along the east shore. Sucker Spring, which is the largest of the three springs, seeps through a 30-m section of rock berm that is part of the Southern Pacific railroad track that was built around 1920. Because the rock berm covered much of the original spawning area, approximately  $4\text{ m}^3$  of gravel were added to the  $20\text{-m}^2$  cobble and boulder area at the spring/lake interface in 1987 to provide additional spawning substrate. Small patches of cobble were added in 1991. The maximum depth at the spawning site is about 1.5 m. Silver Building and Ouxy springs are north of Sucker Spring (0.1 and 1.0 km, respectively). Both of these springs have less flow, encompass a smaller area ( $<15\text{ m}^2$ ), and are shallower ( $<0.7$  m) than Sucker Spring, but have similar cobble and gravel substrate. The temperature of water from all three springs is  $12\text{-}16^\circ\text{C}$ , but water temperature at the spawning sites is dependent on the mixture of lake and spring water, which varies with wind speed and direction. Another east-shore spring, Barkley, was historically used for spawning by Lost River suckers but has been vacant since the late 1970s. In the northwest corner of the lake, Harriman Spring was once used by large numbers of suckers, but the last known usage was by a few Lost River suckers in late March 1974 (Andreasen 1975).

## Methods

*Williamson-Sprague river system.*— Our studies of the spawning migration of Lost River and shortnose suckers in the Williamson River began with trial efforts in 1994, followed by routine sampling from 1995 to 1998. Trammel nets were fished from late February through May at various sites in the lower 1 km of the Williamson River, but in 1997 and 1998 most fishing was at a site 1 km upstream from the river mouth which, based on previous experience, yielded more fish than other sites. Each net was 1.8 m high x 91 m long, with two outer panels (30 cm bar mesh), an inner panel (3.8 cm bar mesh), a foamcore float line, and a 23-kg, leadcore bottom line. Nets were usually

positioned perpendicular to the flow and retrieved after 60-90 minutes. Fish were cut from the mesh and placed in a mesh cage next to the boat and processed within 30 minutes of capture. Processing entailed species and sex identification, measurement of fork length (mm) and weight (g), and inspection for tags (passive integrated transponders (PIT tags) and Floy tags). If a sucker did not have a PIT tag, one was inserted with a hypodermic needle into musculature either just below the dorsal fin (1994 and 1995) or along the ventral surface of the pelvic girdle (1996-1998). Starting in 1996, we also conducted detailed external inspections for physical afflictions (e.g., deformities, infections, and parasites) and release of gametes after stroking the abdomen.

Gender identification was generally not problematic because adult males were readily identified by tubercles and extruded milt. Males also tended to have larger anal fins than females relative to body size. The distinction of small females from juveniles was less clear, but length frequency analysis showed that fish identified as juveniles were smaller than males, which were smaller than females. This is consistent with expectations given that gender-based size differences (males smaller than females) are a dominant feature of many catostomids (Brown and Graham 1954, Geen et al. 1966, Bailey 1969, Jenkins 1970, Scott and Crossman 1973, Corbett and Powles 1983, Burr and Heidinger 1983, Curry and Spacie 1984, Sule and Skelly 1985, Scopettone et al. 1986).

To identify any diel patterns in sucker migration in the Williamson River, trammel nets were fished continuously for 70 hours in 1997 (starting 7 May at 0900 h) and 1998 (starting 5 May 0830 h). Three nets positioned about 100 m apart were fished 1 km upstream from the river mouth. Each net extended from one side of the river to the other. Nets were retrieved and reset one at a time so that at least two nets were in the water during the entire sample period.

The catch per unit effort (CPUE; number of fish per hour) of adult Lost River and shortnose suckers was calculated for each net fished from 1995-1998. For the diel migration study, suckers that had been previously captured during the 70-hour sample period were not included in calculations of CPUE. To compare the annual abundance of adult suckers captured in the lower 1 km of the Williamson River, an index of abundance (A) was computed for each species as follows:

$$A = \sum_{i=x}^y \overline{\text{CPUE}_i}$$

where  $i$  = day of the year,  
 $x$  = first day sampled, and  
 $y$  = last day sampled.

For days not sampled, we used linear interpolation to estimate the daily mean CPUE. In essence, the index of abundance represents the area under the "date vs. CPUE" curve. For purposes of analyses, all shortnose suckers  $\geq 300$  mm, male Lost River suckers  $\geq 400$  mm, and female Lost River suckers  $\geq 500$  mm were considered adults. To standardize comparisons among years, only nets retrieved between 0800 and 1900 hours were used to calculate daily mean CPUE. Nets that did not fish properly due to high water or other factors were excluded from calculations.

Water temperature in the Williamson River was recorded each year from 1995 to 1998 with a temperature logger (StowAway<sup>TM</sup>, Onset Computer Corporation) placed 0.6-1.0 km upstream from the lake at a water depth of 0.5 m. Water discharge of the Williamson River was recorded at a gaging station located below the confluence of the Sprague River, near Chiloquin, Oregon. Data for this station (#11502500) were obtained from the Water Resources Division of the U.S. Geological Survey.

In addition to our data, we compiled and analyzed raw data from two unpublished studies of spawning suckers in the Williamson-Sprague river system. The first data set came from C. Bienz (Klamath Tribes) and J. Ziller (Oregon Department of Fish and Game). In 1984 and 1985, they used a boat-mounted electroshocker (Coffelt model VVP IIC) to systematically sample the 7.6-km section from the Sprague River Dam downstream beyond the confluence of the Williamson River to Waterwheel Park, just downstream of the Highway 97 bridge. Fish were processed and released at about 400-m intervals. Processing included determination of species and sex, measurement of fork length to the nearest mm, and insertion of a Floy dart tag below the dorsal fin. The second data set was collected by the U.S. Fish and Wildlife Service (1987-1988) and the Klamath Tribes (1989-1991). These data consisted of sporadic electrofishing at several

sites along the 7.6-km reach electrofished in 1984 and 1985. Captured fish were processed as described above. Sometimes one species was targeted by sampling areas of the river where the desired species predominated.

*Springs.*— In most years from 1987-1998, spawning was monitored at one or more of three springs (Sucker, Ouxy, and Silver Building) located along the east shore of Upper Klamath Lake. Fish were captured with trammel nets (described above) or with a large seine (9 m x 30 m; 2.5 cm bar mesh) spread over the spawning substrate and later lifted to corral fish that had entered the area. Fish were processed as described above for the Williamson River, except that some fish were marked with Floy dart tags inserted below the dorsal fin instead of PIT tags.

*Upper Klamath Lake.*— In 1997 and 1998, trammel nets were used to examine the lakewide distribution of adult suckers during the spawning season (March through May). Nets were fished a total of 993 hours at 29 sites throughout the lake in 1997, and 574 hours at 26 sites in 1998. Nets were usually set for 1-2 hours. Fish were processed as described for the Williamson River.

*Fecundity.* — Fecundity was calculated for seven Lost River and six shortnose suckers collected from the spawning migrations up the Williamson and Sprague rivers in 1987 and 1988. To supplement the small sample sizes, fecundity was also estimated for several suckers from Sucker Spring and Copco Reservoir (downstream from Upper Klamath Lake). Calculations were made gravimetrically or by volumetric displacement (Snyder 1983) based on six 1-mg or 1-ml subsamples removed from the anterior, middle, and posterior region of each ovary (two subsamples per region). The mean number of eggs per subsample was extrapolated to the total weight or volume of the ovaries to estimate fecundity.

## Results and Discussion

### *Timing of Migration and Spawning*

In the Williamson River and lower Sprague River, most spawning by Lost River and shortnose suckers was during a 5-week period that started within the first three weeks of April (Figure 2). Peak spawning varied among years from mid April to early May for

both species, which is consistent with observations made from 1968-1979 by biologists from the Oregon Department of Fish and Wildlife (unpublished memoranda). We inferred the time of peak spawning from the relative abundance of suckers captured near the spawning areas in 1984 and 1985, and from the relative CPUE of suckers captured in the lower Williamson River from 1995 to 1998 (Figure 2). Because both pre- and post-spawn suckers were captured in the lower river, observations of male ripeness were used to help infer the time of spawning. For example, in 1997 the highest CPUE of shortnose suckers occurred 13 May, but many of the males appeared spawned out (Figure 3; thus, peak spawning probably occurred earlier. Because of smaller sample sizes, statements about male ripeness of Lost River suckers were limited to the observations that spawned-out males were not captured in the lower Williamson River until the fourth week of April in 1996 and 1998, and the second week of May in 1997.

Data suggest Lost River suckers may have an early run of fish that spawn in the upper Sprague River, and a later run of fish that spawns in the Williamson River and the lower Sprague River. The CPUE of Lost River suckers in the lower Williamson River had a peak in mid March each year from 1995-1997 (Figure 2) and in the third week of March 1995, Lost River suckers were observed spawning at Kirk Spring in the upper Sprague River (rkm 128; L. Dunsmoor, Klamath Tribes, personal communication). There was no concurrent sampling at spawning areas in the Williamson and lower Sprague rivers from 1995-1998, but sampling in 1984 and 1985 indicated that Lost River suckers were scarce in March (only three fish were captured in 10 sample days).

A tendency for larger Lost River suckers to spawn earlier than smaller conspecifics was observed in the Williamson River and at the springs (Figure 4). For example, 97% of fish captured at the springs in March 1993 were greater than 550 mm, compared to 45% of fish captured in May. Similar patterns of larger and/or older individuals migrating or spawning earlier than other conspecifics have been noted for other species such as anadromous brook charr *Salvelinus fontinalis* (Castonguay et al. 1982), landlocked Atlantic salmon *Salmo salar* (Trépanier et al. 1996), smallmouth bass *Micropterus dolomieu* (Ridgway et al. 1991, Baylis et al. 1993, Carlander 1977, Goodgame and Miranda 1993), and ruffe *Gymnocephalus cernuus* (Leino and McCormick 1997).

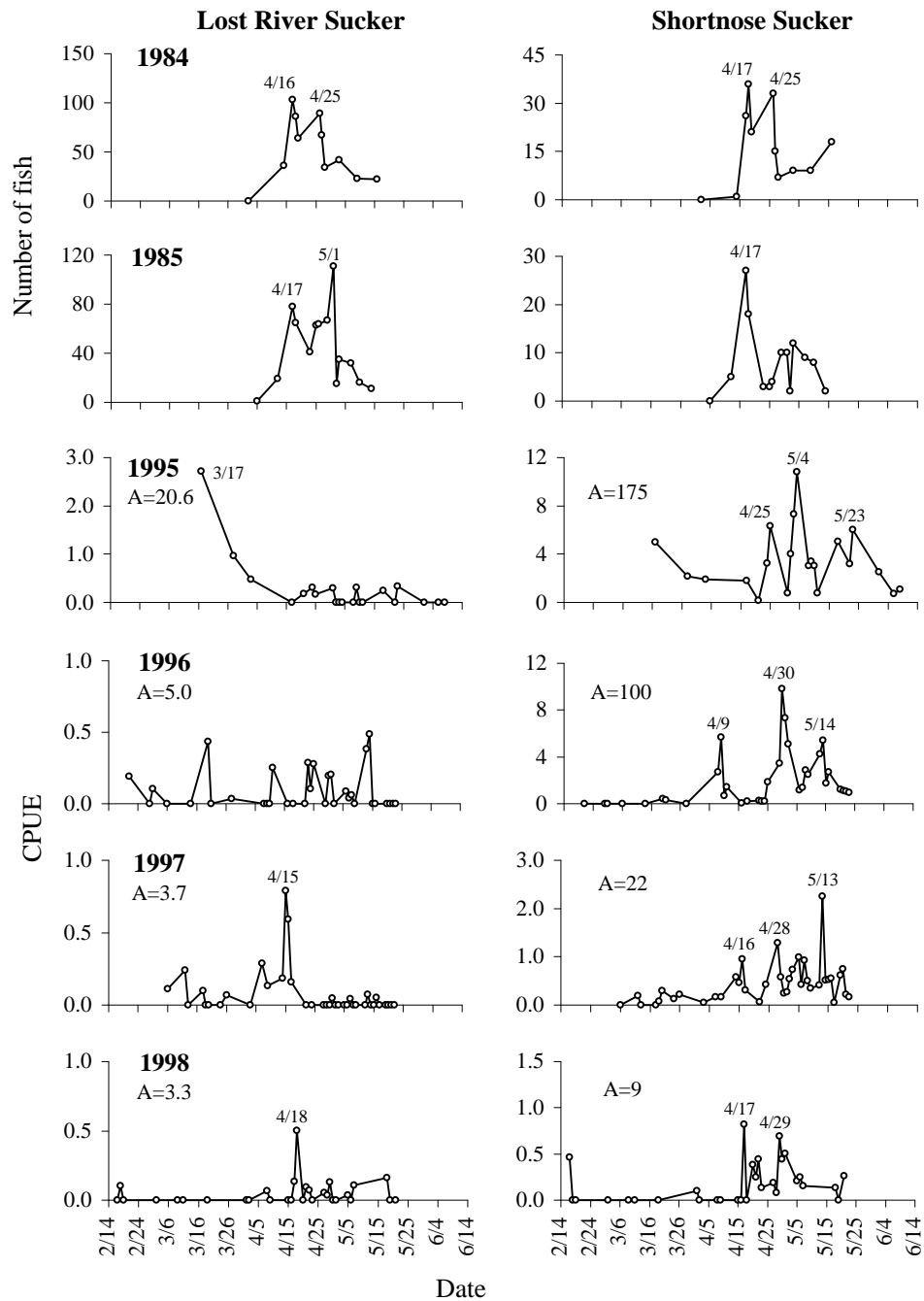


Figure 2. The abundance and mean catch per unit effort (CPUE; number of fish per trammel net per hour) of adult Lost River and shortnose suckers captured by electrofishing (1984-1991) and trammel nets (1994-1998) in the Williamson and Sprague rivers. The abundance index (A) represents the sum of the daily mean CPUEs (see Methods).

The 3-day diel studies indicated that migration of Lost River and shortnose suckers was frequently several times higher in early morning (0500-0730 h) and evening (1800-2200 h) than other times of the day (Figure 5). The major peaks in catches usually lasted less than two hours and were followed by sharply decreased catches. Greater migration in evening hours relative to other times of the day has also been observed for a number of other suckers (*Catostomus commersoni* and *C. catostomus*, Geen et al. 1966; *Chasmistes cujus*, Scopettone et al. 1986).

Lost River suckers were captured at springs along the east shore of Upper Klamath Lake from late February through mid May (Appendix A). Anglers noted that in some years, Lost River suckers were present at Sucker Spring in early February. Fish capture and visual observations indicated that peak spawning by Lost River suckers was usually in mid March to mid April at Sucker Spring, and that spawning sometimes extended into mid May (Appendix A). Sampling at Ouxy and Silver Building springs was too infrequent to assess seasonal changes in fish abundance. Even at Sucker Spring, which was sampled most intensively, temporal changes in abundance may have been missed because there was no consistent sampling throughout an entire spawning season. In addition, fish capture at the springs was not considered a good indicator of fish abundance because catchability varied widely, both within and among days. Variables that affected catchability included weather conditions (e.g., waves, cloud cover), proximity to peak spawning, and diel timing of sampling.

Shortnose suckers were generally captured at the springs from late March through late May, but sampling was not sufficient to assess changes in abundance or the time of peak spawning within a given spawning season (Appendix A). Shortnose suckers were conspicuously absent from samples between 1987 and 1991, possibly because the adult population size was lower than in later years (see below).

### *Migration Cues*

Increasing water temperature seems to be an important cue for upstream migration of Lost River and shortnose suckers. From 1995-1998, peaks in CPUE of Lost River and shortnose suckers in the lower Williamson River corresponded to peaks in water temperature at 10-15°C (Figure 6 the peak at 18°C was largely spawned-out,

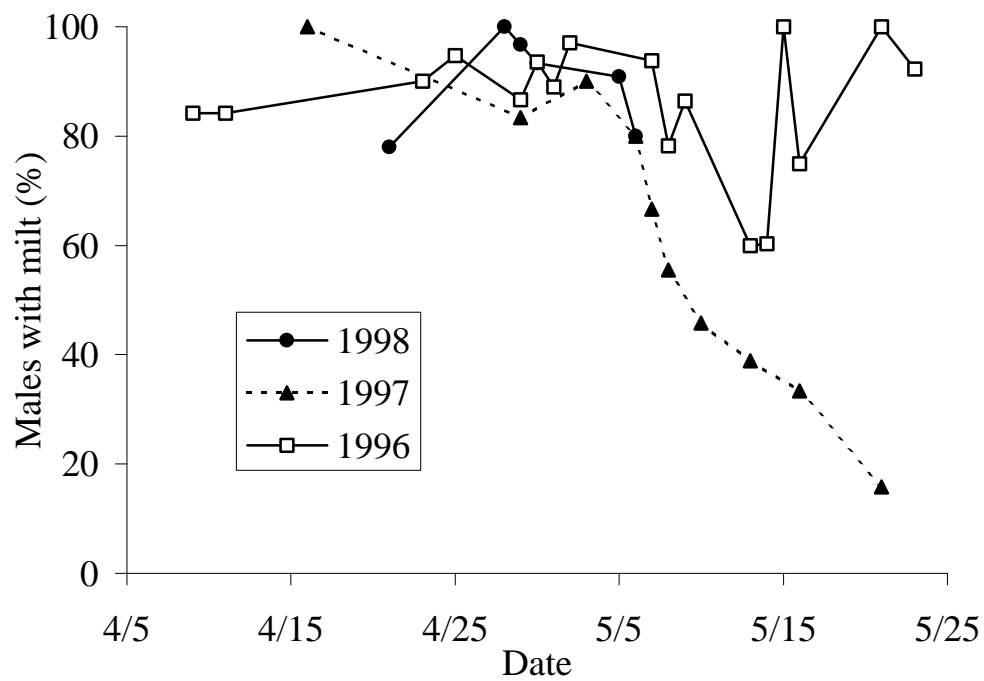


Figure 3. Proportion of male shortnose suckers captured in the lower Williamson River that released milt. If less than 10 fish were captured in a day, data were either combined with immediately adjacent sample days (whenever possible) or excluded.

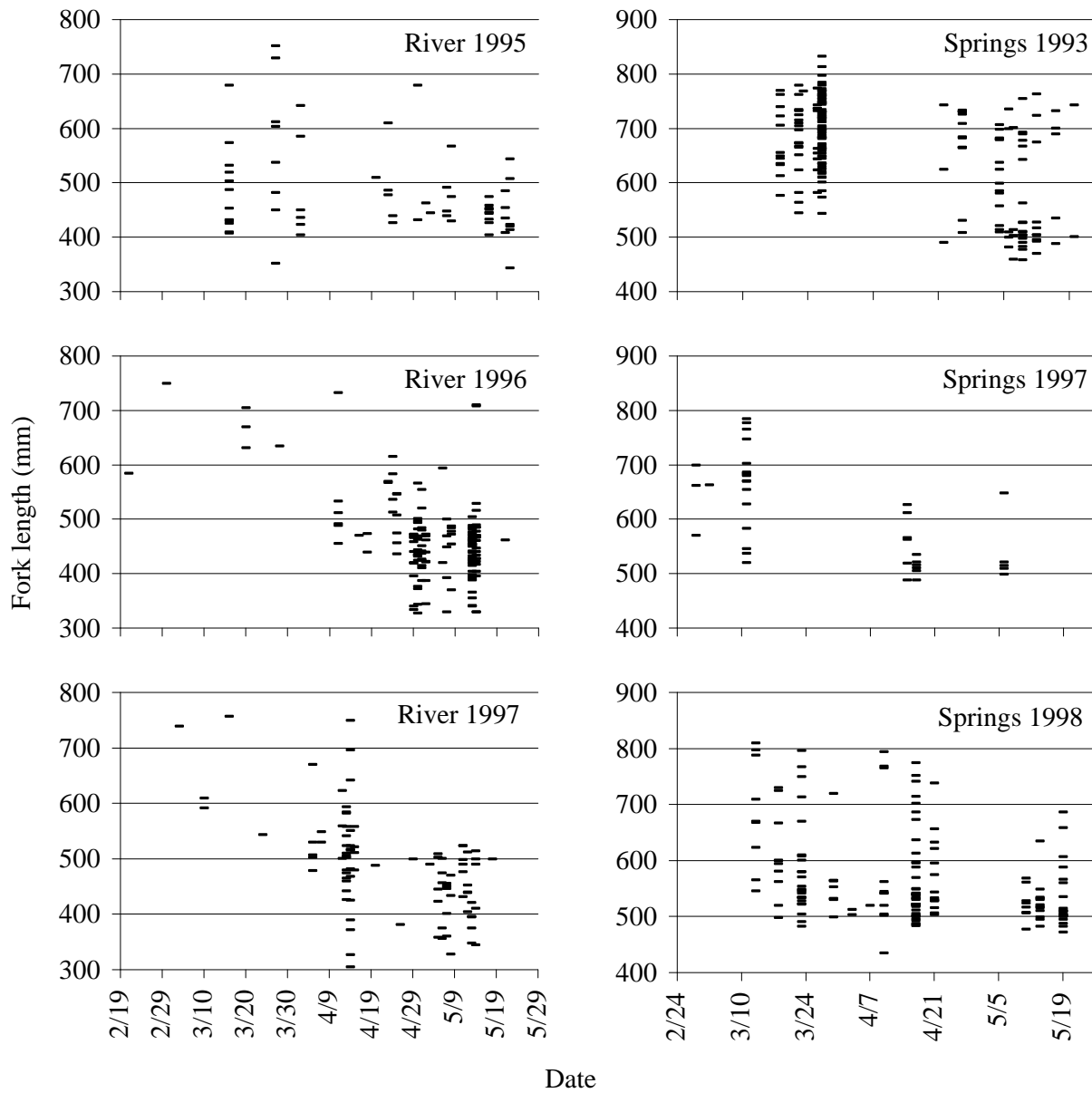


Figure 4. Temporal pattern of the size of Lost River suckers captured in the lower Williamson River and at springs (Sucker, Silver Building, and Ouxy) along the east shore of Upper Klamath Lake.

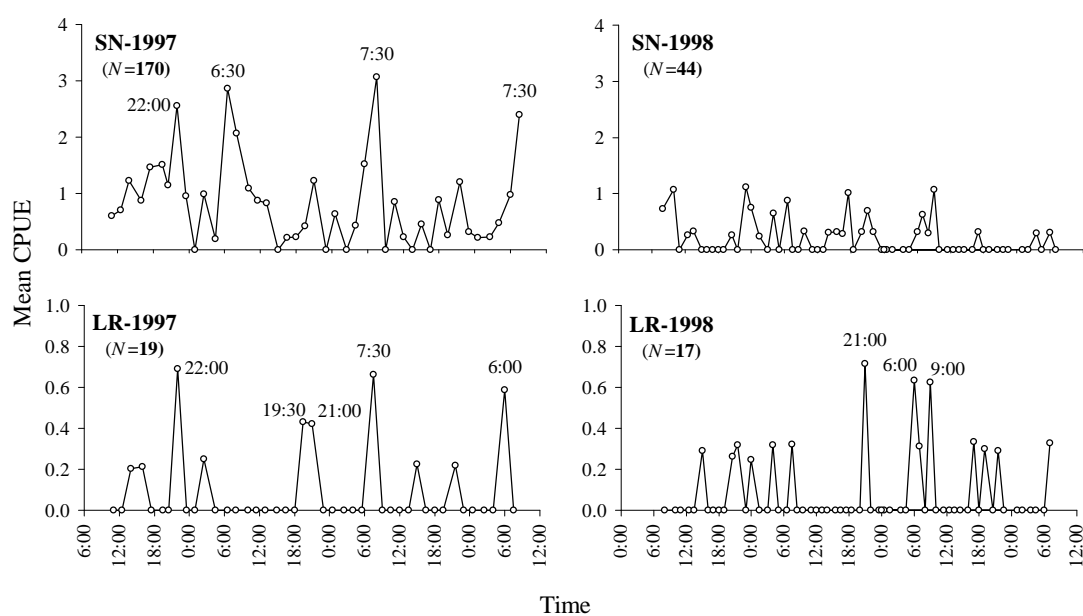


Figure 5. Diel pattern of fish capture in trammel nets located 1 km upstream from the mouth of the Williamson River in 1997 (7-10 May) and 1998 (5-8 May). Catch values represent the mean catch per unit effort (CPUE; number of fish per trammel net per hour) of three nets.

downstream migrants). Temperatures of 10-15°C have also been associated with increased spawning migration of other catostomids (Geen et al. 1966, Corbett and Powles 1983, Scoppettone et al. 1986). Temperature preference is probably an adaptation to maximize reproductive success. Scoppettone et al. (1993) found that for *C. cujus* a temperature regime of 9-15°C yielded greater larval survival to swim-up than warmer temperature regimes (e.g., 12-18°C). Increased water discharge has been considered an important cue for spawning migration in some species (Banks 1969), but observations in our study were equivocal (Figure 6).

### *Spawning Behavior*

Spawning behavior of Lost River and shortnose suckers was observed in the Williamson River, the Sprague River, Sucker Spring, and Ouxy Spring (shortnose only). At Sucker Spring, fish usually moved into the spawning area shortly after sunset, although spawning was also observed during the day. The most common spawning alignment at the springs and rivers was one female flanked by two males, as observed for cui-ui (Scoppettone et al. 1983), but up to seven males were observed spawning with a single female. Each spawning act was indicated by rapid body contractions, extension of fins, and extrusion of gametes. Most spawning acts lasted less than six seconds. Individual females spawned at least several times a night and usually spawned in the same general location. After each spawning act the female usually retreated to deeper water for several minutes before returning to spawn again. Males tended to remain on or immediately adjacent to the spawning area and would spawn with other active females. No aggressive behavior was observed among fish. Occasionally more than one female would spawn in a group. Contrary to spawning observations made by Golden (1969), Lost River suckers spawned near the stream bottom. When gravel was available, eggs were buried within the top several centimeters in the manner described for cui-ui (Scoppettone et al. 1983). When spawning over cobble and compacted substrate, eggs fell between crevices or were washed downstream.

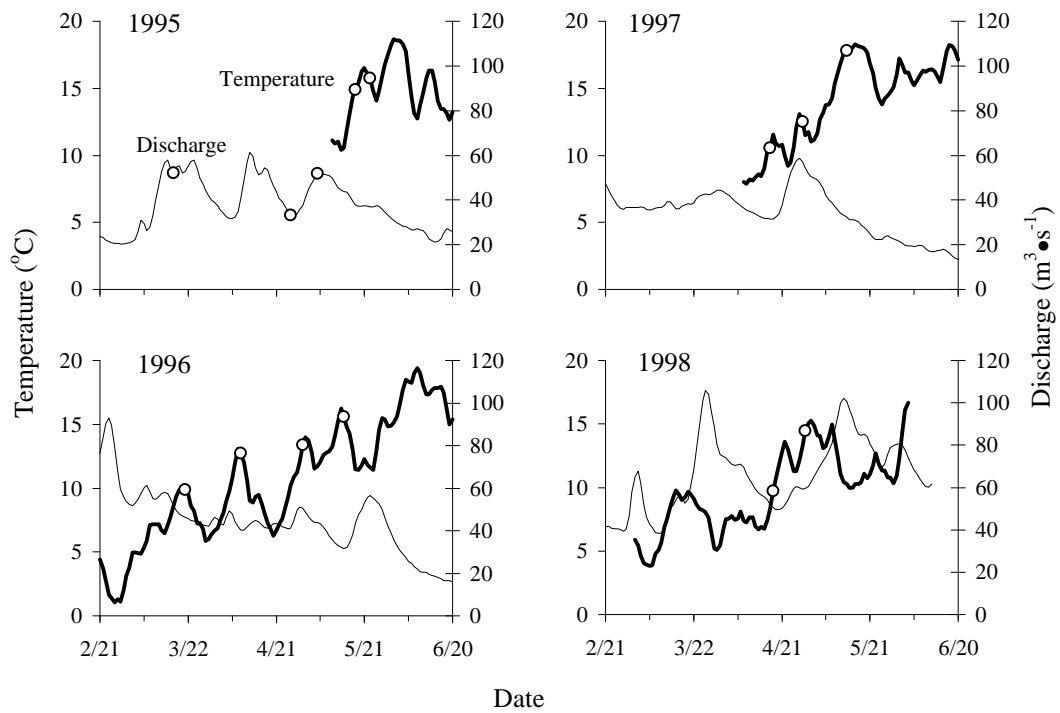


Figure 6. Mean daily water temperature and discharge in the lower Williamson River, 1995-1998. Open circles correspond to peaks in the capture of Lost River and/or shortnose suckers in the lower Williamson River (see Figure 2).

*Length of Time Individuals Occupy Spawning Areas*

Most Lost River and shortnose suckers probably occupy spawning areas for less than half the spawning season. When Lost River and shortnose suckers were captured near spawning areas on different days within the same spawning season, the two capture dates were usually within 10 days of each other. This was true for both species at the springs (44 of 50 Lost River, five of seven shortnose) and for Lost River suckers in the Williamson-Sprague river system (18 of 20 Lost River, one of four shortnose). The longest length of time between two capture dates within the same spawning season was 14 days for a Lost River sucker and 29 days for a shortnose sucker in the Williamson-Sprague river system, and 25 days for a Lost River sucker and 16 days for a shortnose sucker at the springs. All four of these latter fish were males. Radio-telemetry data collected from 1993-1996 indicated that most suckers (three of four Lost River and eight of nine shortnose) spent at least two to three weeks in the Williamson-Sprague river system, but not necessarily at the spawning areas (M. Buettner, unpublished data).

*Size and Age at Maturity*

Aging data from suckers collected in fish kills in 1995-1997 identified a dominant year class of Lost River and shortnose suckers in 1991 (Perkins and Scoppettone, unpublished data), which offered a good opportunity to determine the size and age at maturity. Suckers were aged using methods described by Casselman (1974) for subcleithra and Scoppettone (1988) for opercles. Ages from opercles were validated by comparison of modal age in consecutive years, and by comparison to ages from otoliths.

Based on data from the 1991 year class, male Lost River suckers began recruitment into the adult population in 1995 at age 4+. The smallest male that released milt was 377 mm, but the modal size of mature males at age 4+ was 465 mm (Figure 7. Substantial recruitment of females from the 1991 year class did not occur until age 7+, at a modal length of 535 mm.

Male and female shortnose suckers began recruitment into the adult population by age 4+. The smallest male that released milt was 270 mm, but the modal size of mature

males at age 4+ was 325 mm; the smallest female that released eggs was 325 mm, but the modal size of mature females at age 4+ was 340 mm (Figure 8). In 1995, the sex ratio of the 1991 year class was skewed towards males (2:1), but in 1996 the sex ratio equalized, which suggests that the majority of the 1991 year class had recruited into the adult population by age 5+.

The size and age at maturity, as determined from recruitment of the 1991 year class, reflect the best available data for Lost River and shortnose suckers, but the maturity schedule of other year classes could be different as a result of population density or compensatory responses to environmental conditions. In some species, such as white sucker (*Catostomus commersoni*), size and age at maturity appear to be inversely related to growth rate (Chen and Harvey 1994, Gagnon et al. 1995). Hence, environmental conditions that affect growth rates affect maturation. Growth rates have not been determined yet for Lost River and shortnose suckers, but indications of variation in size and age at maturity exist. In 1987 and 1988, there appeared to be recruitment of new Lost River and shortnose suckers into the spawning populations of the Williamson and Sprague rivers, and these fish were larger than the new recruits observed in 1995. In contrast, a cohort of male shortnose suckers suspected to be age 5+ began recruiting in 1998 at a smaller size (modal size = 305 mm) than the 4-year old males in 1995 (modal size = 350 mm; Figure 8).

### *Fecundity*

Fecundity studies of Lost River and shortnose suckers, including our own, have been limited to few fish. To provide a better indication of fecundity, we compiled data from a variety of sources (Appendix B). Fecundity estimates were variable, ranging from 44,000-236,000 eggs per female Lost River sucker and 18,000-72,000 eggs per female shortnose sucker. Linear regression indicated a weak, but significant ( $P < 0.05$ ) positive relationship between fish length and fecundity ( $R^2 = 0.36$  for Lost River suckers;  $R^2 = 0.27$  for shortnose sucker) (Figure 9). We suspect that some factors that caused variation in the length-fecundity relationship of Lost River and shortnose suckers were fish age, previous spawning history, and methodological differences among studies.

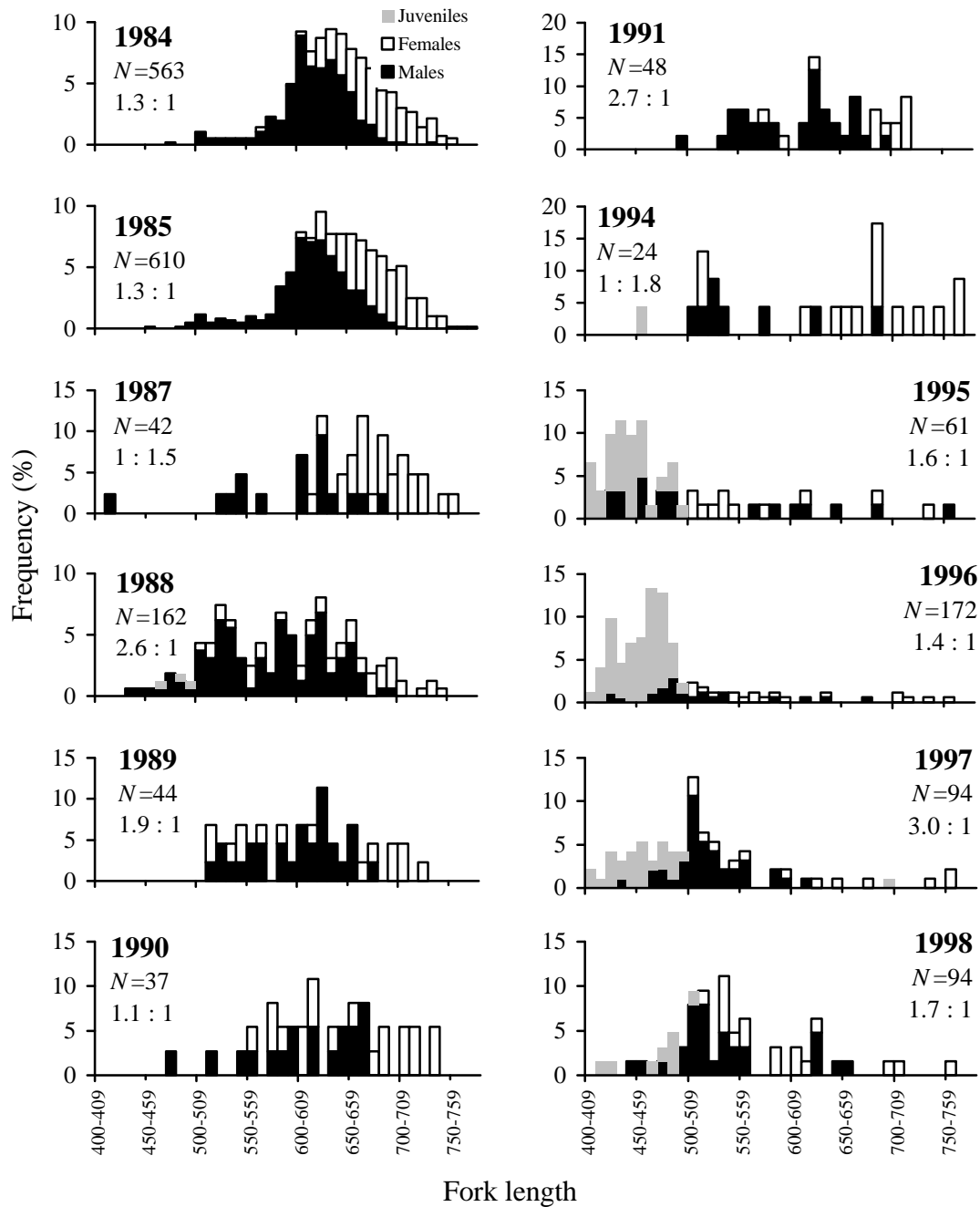


Figure 7. Size distribution and sex ratio (male:female) of Lost River suckers captured by electrofishing (1984-1991) and trammel nets (1994-1998) in the Williamson and Sprague rivers. Fifty-two fish less than 400 mm are not shown, 46 of which were captured in 1996-98.

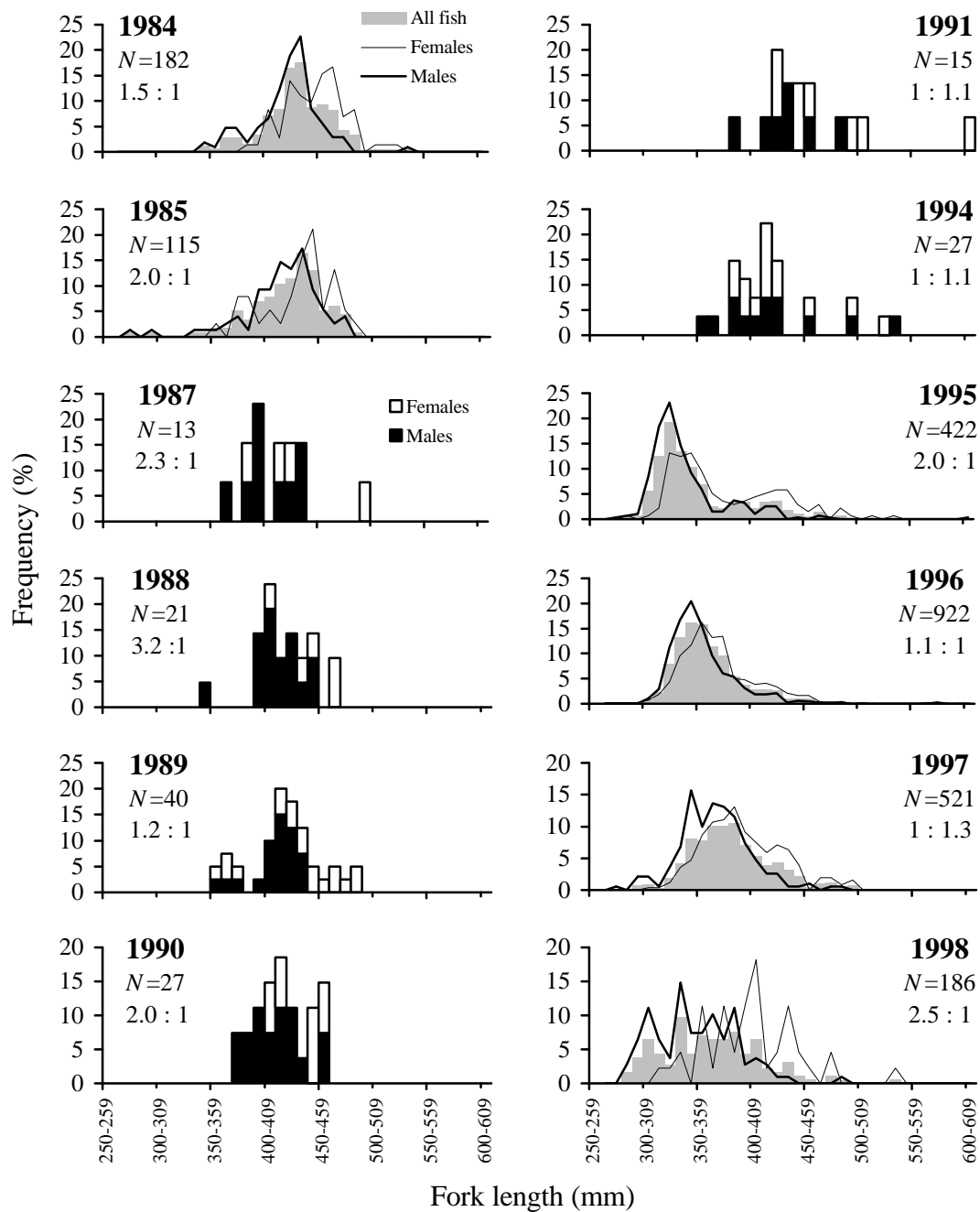


Figure 8. Size distribution and sex ratio (male:female) of shortnose suckers captured by electrofishing (1984-1991) and trammel nets (1994-1998) in the Williamson and Sprague rivers.

### *Iteroparity*

The recapture of tagged Lost River and shortnose suckers indicated that individual males and females commonly spawned in consecutive years. The capture of individual Lost River suckers in two consecutive years occurred 100 times at the springs and 17 times in the Williamson and Sprague rivers. Fourteen Lost River suckers were captured in three consecutive years and another 36 were captured at the springs in three to six different years over a period of up to 10 years. Much less recapture data exist for shortnose suckers, which may be a function of effort and the proportion of the population sampled, but capture in two consecutive years occurred four times in the rivers; at the springs, three shortnose suckers were recaptured two years after their initial capture.

Whether all adult Lost River and shortnose suckers spawn every year is not known. Geen et al. (1966) determined that although some longnose and white suckers spawned in several successive years, only 25-50% of the adult population spawned each year. Our trammel netting during the spawning season in 1997 and 1998 captured adult suckers throughout the lake rather than at known spawning areas (see below), but some fish were recaptured at spawning areas later in spring.

### *Fish Condition*

Shortnose and Lost River suckers from Upper Klamath Lake exhibited physical afflictions that included eroded, deformed, and missing fins; lordosis (forward curvature of the spine); pugheads; multiple types of water mold infections; reddening of the fins and body caused by hemorrhage; cloudiness of the skin caused by increased mucous production; pigmentation loss; parasitic infections of the body and gills; lamprey wounds; ulcers; cysts; gas emboli in the eyes; exophthalmos (protuding eye); and cataracts. The frequency of many afflictions was significantly greater in 1997 and 1998 than 1995 and 1996 ( $P < 0.05$ ; Table 1). Of the adult suckers captured from the Williamson River in April and May, 65-92% of fish had some type of affliction in 1997-98, whereas 19-21% had afflictions in 1996 (data for 1995 were incomplete). Unlike previous years, nine dead Lost River and four dead shortnose suckers were encountered in spring 1997 and

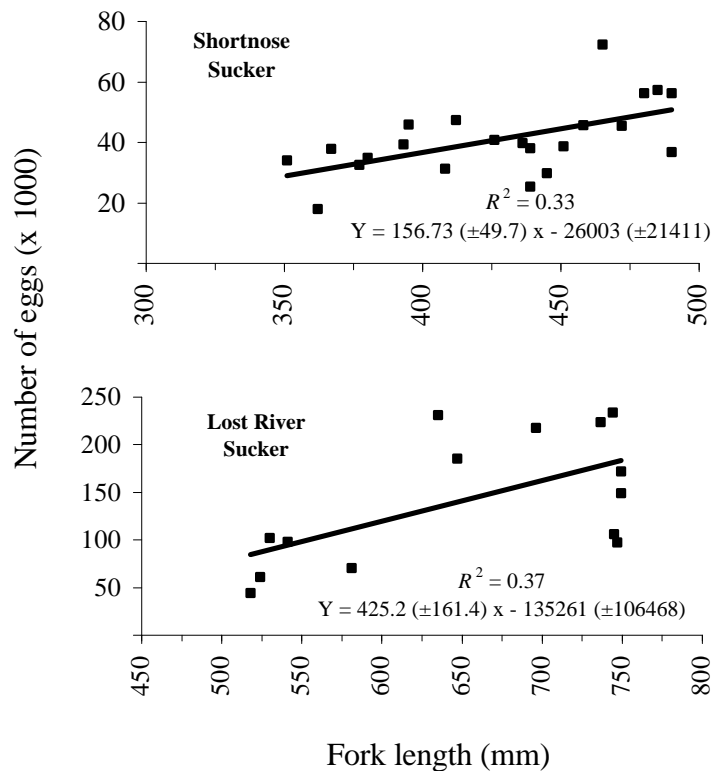


Figure 9. Fecundity (number of eggs per fish) of Lost River and shortnose suckers. Data were compiled from several sources (see Appendix B). The slopes of the regression lines were significantly greater than zero ( $P < 0.05$ ). Standard errors are given in parentheses.

1998, which is consistent with expectations that a high rate of physical afflictions would be associated with increased mortality. Many of the afflictions observed can result from poor water quality, bacteria, viruses, fungi, parasites, nutritional deficiencies, toxicoses, and genetic inheritance (Noga 1996). Stress associated with poor water quality is implicated as a major contributor to the fish afflictions because the high rates of afflictions occurred after summers with poor water quality and severe fish kills.

To characterize the length-weight relationship of adult Lost River and shortnose suckers, we calculated regression equations for males and females captured from the lower Williamson River and the springs between 1 March and 10 May 1996 (Figure 10). Data from this year were used because sample sizes were greater than in 1995, and because the condition of fish in later years may have been influenced by stressful summer conditions that caused fish kills. The dates were selected to target fish in spawning condition and minimize the number of post-spawn fish.

#### *Lakewide Distribution of Adults During Spawning Season*

Sampling from March through May, 1997-98, revealed a low density, but widespread distribution of adult suckers throughout Upper Klamath Lake. Only 16% and 48% of the sites produced Lost River and shortnose suckers, respectively, with capture sites spread throughout the lake. In 1997, 42 Lost River suckers were captured from nine sites and 297 shortnose suckers were captured from 16 sites. In 1998, 25 Lost River suckers were captured from five sites and 400 shortnose suckers were captured from 14 sites. The mean CPUE of the capture sites (sites without fish excluded) was 0.31 shortnose suckers per net hour (SD=0.38) and 0.069 Lost River suckers per net hour (SD=0.082). The sites that were consistently most productive were Squaw Point (mean CPUE=0.168) and Eagle Ridge (0.13) for Lost River suckers, and Eagle Ridge (1.75), Modoc Point (0.74), and Goose Bay (0.64) for shortnose suckers. Even at these sites, catch rates were prone to large day-to-day fluctuations. Some of these fluctuations appeared to be weather related, with stable weather yielding higher catches. Evidence that conspecifics were non-randomly distributed included variation in the size distribution of fish among sites (e.g., in 1998, 88% of shortnose suckers 300-350 mm came from

TABLE 1. - Prevalence (%) of afflictions noted from gross examination of Lost River and shortnose suckers captured from the Williamson River in April and May, 1996-1998. Afflictions that occurred in less than 1% of fish were not listed. Significant differences in the prevalence of afflictions within species are indicated by superscript letters that match (z-test,  $P < 0.05$ ).

	Year	N	Any affliction	Lamprey wound(s)	<i>Lernaea</i>	Nem-atode	Other parasite	Absent or deformed fin	Cataract(s)	Exophthalmos	Deformity*	Emaciated	Ulcer
Shortnose sucker	1995	331	---	10 <sup>a</sup>	3 <sup>a</sup>	---	---	---	2 <sup>a</sup>	---	---	---	---
	1996	918	19 <sup>a</sup>	8 <sup>b,c</sup>	6 <sup>a</sup>	0 <sup>a</sup>	0 <sup>a,b</sup>	4 <sup>a</sup>	2 <sup>b</sup>	0 <sup>a,b</sup>	1 <sup>a,b</sup>	0 <sup>a,b</sup>	0 <sup>a</sup>
	1997	512	92 <sup>a</sup>	16 <sup>a,b</sup>	85 <sup>a</sup>	3 <sup>a</sup>	1 <sup>a</sup>	8 <sup>a</sup>	7 <sup>a,b</sup>	2 <sup>a</sup>	3 <sup>a</sup>	1 <sup>a</sup>	10 <sup>a</sup>
	1998	181	83 <sup>a</sup>	28 <sup>a,c</sup>	75 <sup>a</sup>	12 <sup>a</sup>	1 <sup>b</sup>	5	4	1 <sup>b</sup>	4 <sup>b</sup>	1 <sup>b</sup>	3 <sup>a</sup>
Lost River sucker	1995	33	---	9 <sup>a</sup>	9 <sup>a</sup>	---	---	---	3	---	---	---	---
	1996	166	21 <sup>a,b</sup>	10 <sup>b</sup>	9 <sup>b</sup>	0	0 <sup>a</sup>	1 <sup>a</sup>	1 <sup>a,b</sup>	0	1	0	0 <sup>a</sup>
	1997	89	69 <sup>a</sup>	17 <sup>c</sup>	58 <sup>a,b</sup>	0	7 <sup>a</sup>	1 <sup>b</sup>	9 <sup>a</sup>	0	2	0	6 <sup>a</sup>
	1998	60	65 <sup>b</sup>	37 <sup>a,b,c</sup>	40 <sup>a,b</sup>	0	0	10 <sup>a,b</sup>	10 <sup>b</sup>	0	2	2	0

\*Includes deformities of the spine, head, mouth, and operculum.

"---" indicates data fields which were not recorded on a consistent basis in 1995.

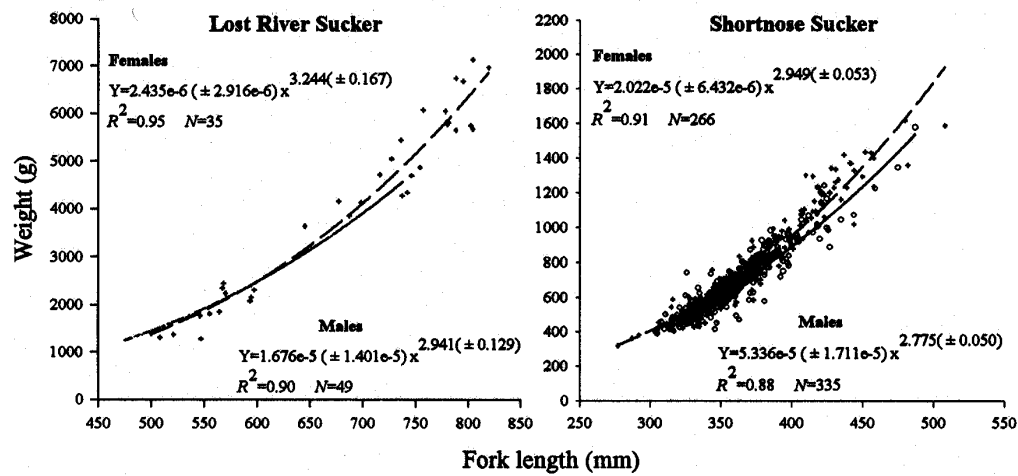


Figure 10. Length-weight relationship of suckers captured from the Williamson River and east-shore springs, 1 March-10 May, 1996. Standard errors are given in parentheses.

Eagle Ridge) and a disproportionately high number of shortnose suckers that were tagged at Modoc Point in 1997 and recaptured at, or near, the same site in 1998.

Male Lost River and shortnose suckers captured in the lake often released milt. These males were captured from early March until early May at a number of widespread sites (e.g., Modoc Point, Bare Island, Squaw Point, and Stone House). Only one female, a shortnose sucker captured 10 March 1997 at Modoc Point, released eggs. Data were not sufficient to infer the location, if any, of spawning sites in the lake.

#### *Demographics-Williamson-Sprague River System*

In 1984 and 1985, the spawning Lost River and shortnose suckers in the Williamson and Sprague rivers were primarily large, old fish, suggesting both species experienced an extended period of minimal adult recruitment (Figures 7 and 8). Shifts toward smaller fish of both species in the late 1980s, and again in the mid to late 1990s suggest recruitment of at least two year classes, with the latter apparently stronger than the former. Aging data from suckers collected in 1995-1998 indicated the 1991 year class dominated the captures of both species in 1995 and subsequent years (Perkins and Scopettone, unpublished data), which is consistent with young-of-year assessments that indicated strong year classes of Lost River and shortnose suckers were produced in 1991 (D. Markle, Oregon State University, personal communication). Subsequent assessments indicated a potential good year class produced in 1993 also, and recruits from this year class may have started to appear in 1998 as indicated by a peak in the size distribution of male shortnose suckers at 305 mm (Figure 8). Cohorts from 1991 and 1993 both correspond to years that had good water quality in the summer relative to other recent years (J. Kann, Klamath Tribes, personal communication). The 1991 year class also corresponds to a year in which the April discharge of the Williamson River was the second lowest on record (1920-1998), which could have benefited reproduction by reducing egg dislodgment from the substrate.

#### *Demographics-Springs*

The size of Lost River suckers, and annual changes in size distribution, were noticeably different between fish from the springs and the Williamson-Sprague river

system. Lost River suckers at the springs were consistently larger than conspecifics in the rivers, except for 1998 (Figures 7 and 11). The size distribution of fish at the springs did not change appreciably from 1987 through 1993, except for an influx of small males in 1993. However, starting in 1996, and becoming more noticeable in 1997 and 1998, the frequency of large and presumably old fish began to decline. Much of the decline in larger fish was probably due to annual fish kills from 1995-1997 that were biased toward larger fish (Perkins et al. 2000).

A new cohort of small adults (mostly males) appeared in 1997 and 1998 and their size distribution corresponded to the 1991 year class that was also seen in the Williamson and Sprague rivers. Although a few females of the 1991 year class may have spawned in 1997 and 1998, substantial recruitment of female suckers has not occurred since pre-1987. Limited data exist for shortnose sucker from the springs, but the size distribution of shortnose suckers at the springs and the rivers appeared similar in 1996 (Figures 8 and 12).

### *Relative Abundance*

In the mid 1980s, the number of adult Lost River and shortnose suckers were perilously low and decreasing (USFWS 1988). Signs that adult numbers might be recovering began in 1995, when the abundance of adult suckers in the Williamson-Sprague river system increased substantially due to an influx of the first recruits from a strong year class (1991). However, annual abundance indices of both species declined substantially in the next three years (Figure 2). The index of adult Lost River suckers captured from the lower Williamson River decreased 76%, 25%, and 11% after 1995, whereas shortnose suckers decreased 43%, 78%, and 60% (Figure 2). The total decrease between 1995 and 1998 was 84% for Lost River suckers and 95% for shortnose suckers. Most, if not all of the decrease in fish numbers was probably due to annual fish kills in 1995, 1996, and 1997. Thousands of adult suckers, as well as other species, were collected from these die-offs, the root cause of which seems to have been poor water quality (Perkins et al. 2000). The effect of the fish kills on the abundance of suckers may have been even worse than indicated by the indices because in the absence of the fish

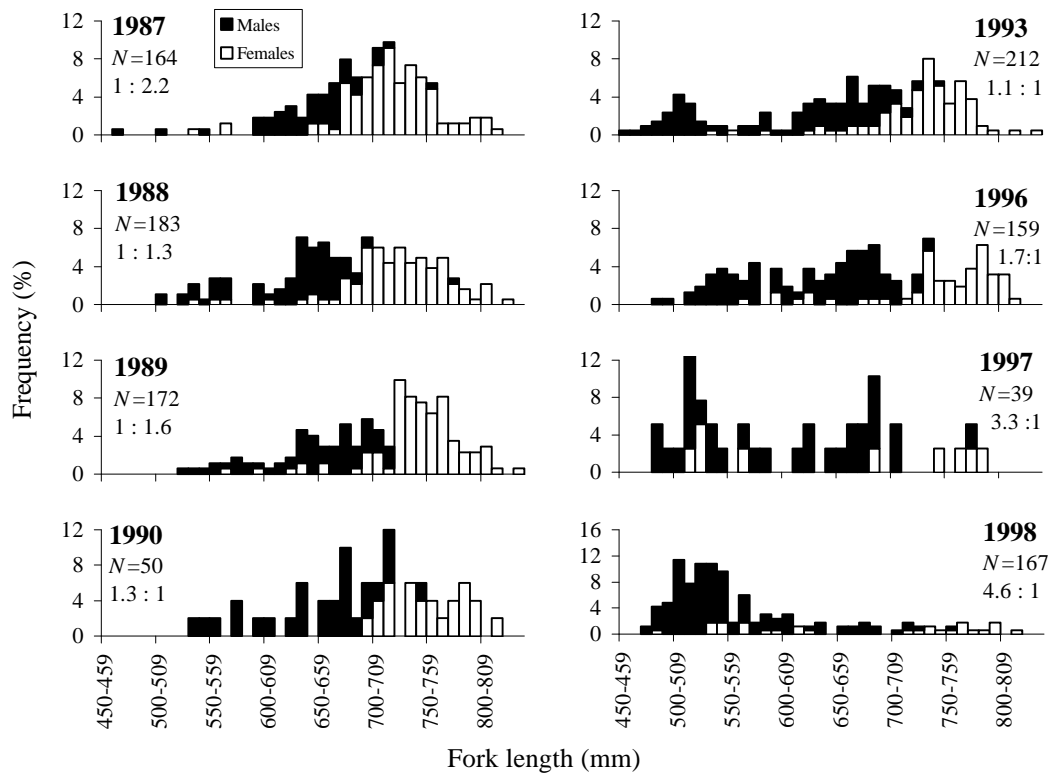


Figure 11. Size distribution and sex ratio (male:female) of Lost River suckers captured at springs (Sucker, Silver Building, and Ouxy) along the east shore of Upper Klamath Lake.

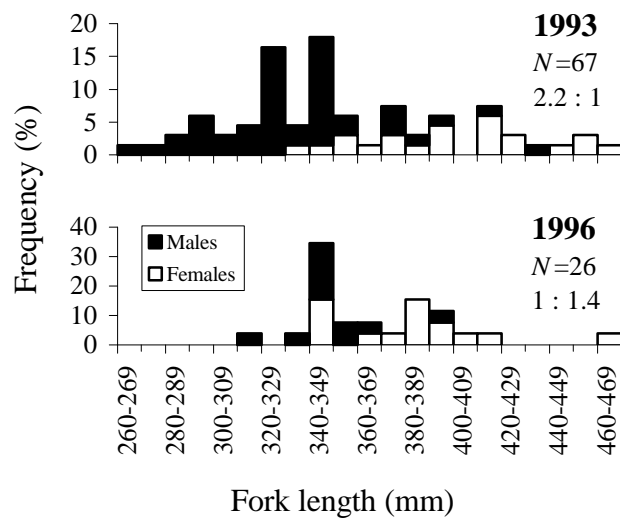


Figure 12. Size distribution and sex ratio (male:female) of shortnose suckers captured at springs (Sucker, Silver Building, and Ouxy) along the east shore of Upper Klamath Lake.

kills, catch rates of adult suckers should have increased from 1995 to 1998 due to recruitment from the 1991 year class.

In addition to mortality from the fish kills, part of the decreased spawner abundance may have been due to a lack of migration by suckers that were in poor condition; however, data suggest that this was not a major contributor. In 1997 and 1998, the length-weight relationship of migratory suckers captured in the stock assessment was not significantly different than that of suckers captured throughout the lake prior to stock assessment ( $P>0.05$ ); thus, migrants did not seem to be in better condition than the population as a whole.

#### *Discreet Stocks within Upper Klamath Lake*

Lost River suckers in Upper Klamath Lake seem to be organized into at least two discreet stocks: one that spawns in the Williamson-Sprague river system, and another that spawns at springs along the east shore of the lake. Of the nearly 400 times that Lost River suckers were recaptured from spawning areas, fish were always recaptured at the same spawning area (i.e., either the Williamson and Sprague rivers or the east-shore springs) as the original capture. Fifty of these fish were captured at the same spawning area in three to six different years. Recapture of tagged Lost River suckers occurred 316 times at Sucker, Ouxy, and Silver Building springs and indicated movement among all three springs, both within and among spawning seasons. The 11 recapture events for shortnose suckers indicated the same; thus, spawning at the three springs appear to be panmictic. Other evidence for stock differentiation between Lost River suckers at the springs and rivers includes differences in the size distribution of adults (Figures 7 and 11), and differences in the time of peak spawning. Accounts of spawning aggregations at other sites suggest existence of additional stocks, at least historically. Data were not sufficient to conclude whether discreet stocks of shortnose suckers also exist.

#### *Management Considerations*

The life history pattern of Lost River and shortnose suckers in Upper Klamath Lake has been severely disrupted by recurrent poor water quality that appears to be the

root cause of the fish kills and death of most adult suckers between 1995 and 1998 (Perkins et al. 2000). Lost River and shortnose suckers exemplify the “periodic strategist” described by Winemiller and Rose (1992), i.e., delayed maturation, intermediate or large size at maturation, high fecundity, small eggs, and seasonal spawning. Species with this life history pattern depend on longevity to persist through extended periods of poor reproductive success. The importance of longevity to Lost River and shortnose suckers is clearly demonstrated when one considers that from 1984 to 1998, only one strong year class recruited into the adult populations. If catastrophic events such as fish kills occur on a regular basis, then the fitness advantage of longevity is not realized by many individuals and population viability is reduced. The annual occurrence of fish kills from 1995-1997 raises concern that the magnitude and frequency of poor water quality have increased to a level that jeopardizes the long-term persistence of the endangered suckers. Eutrophication in Upper Klamath Lake has increased since development of the watershed, and for the past 40 years near-monoculture blooms of *A. flos-aquae* have occurred during summer and fall, whereas previously a diverse algal assemblage occurred (Miller and Tash 1967, Kann 1998). Hence, for the past several decades both species may have experienced reduced survival (of all life stages) that has reduced population viability. Given the obvious water quality problems in Upper Klamath Lake, one of the most important aspects of conservation efforts needs to be improvement of water quality. The vulnerability of populations in Upper Klamath Lake also highlights the importance of protecting and enhancing the few populations of Lost River and shortnose suckers found in other waters.

### Acknowledgments

This work was supported by the Bureau of Reclamation (Interagency Agreement 4-AA-20-12160), the Biological Resources Division of the U.S. Geological Survey, the U.S. Fish and Wildlife Service, the Klamath Tribes, and the Oregon Department of Fish and Wildlife. This manuscript is the result of tremendous effort, dedication, and expertise contributed by the following people: G. Apke, C. Bienz, J. Connor, L. Dunsmoor, A. Franklin, M. Green, J. Harvey, D. Herrera, L. Hill, P. Kappes, D. Larson,

C. Mace, M. Moore, B. Peck, B. Nielsen, P. Rissler, S. Shea, T. Vercolon, D. Waldeck, J. Whiteaker, and J. Ziller. The manuscript benefited greatly from discussions with biologists at the Klamath Field Station and the Klamath Tribes. The Klamath Tribes contributed greatly to monitoring at the springs in many years. Helpful comments were provided by B. Letcher and three anonymous reviewers. Assistance with maps and GIS databases were provided by M. Neuman and D. Simon.

## References

- Andreasen, J. K. 1975. Systematics and status of the family Catostomidae in Southern Oregon. Doctoral dissertation. Oregon State University, Corvallis.
- Bailey, M. M. 1969. Age, growth, and maturity of the longnose sucker *Catostomus catostomus*, of western Lake Superior. Journal of the Fisheries Research Board of Canada 26:1289-1299.
- Banks, J. W. 1969. A review of the literature on the upstream migration of adult salmonids. Journal of Fish Biology 1:85-136.
- Baylis, J. R., D. D. Wiegmann, and M. H. Hoff. 1993. Alternating life histories of smallmouth bass. Transactions of the American Fisheries Society 122:500-510.
- Brown, C. J. D., and R. J. Graham. 1954. Observations on the longnose sucker in Yellowstone Lake. Transactions of the American Fisheries Society 83:38-46.
- Burr, B. M., and R. C. Heidinger. 1983. Reproductive behavior of the bigmouth buffalo *Ictiobus cyprinellus* in Crab Orchard Lake, Illinois. American Midland Naturalist 110:220-221.
- Carlander, K. D. 1977. Handbook of freshwater fishery biology, volume 2. Iowa State University Press, Ames.
- Casselman, J. M. 1974. Analysis of hard tissues of pike *Esox lucius* L. with special reference to age and growth. Pages 13-27 in T. B. Bagenal, editor. Ageing of fish. Gresham Press, Old Woking, England.
- Castonguay, M., G. J. FitzGerald, and Y. Côté. 1982. Life history and movements of anadromous brook charr, *Salvelinus fontinalis*, in the St-Jean River, Gaspé, Quebec. Canadian Journal of Zoology 60:3084-3091.
- Chen Y., and H. H. Harvey. 1994. Maturation of white sucker, *Catostomus commersoni*, populations in Ontario. Canadian Journal of Fisheries and Aquatic Sciences 51:2066-2076.
- Cope, E. D. 1884. On the fishes of the Recent and Pliocene lakes of the western part of the Great Basin, and of the Idaho Pliocene lake. Proceedings of the Academy of Natural Sciences of Philadelphia 35 (1883):134-167.

- Corbett, B., and P. W. Powles. 1983. Spawning and early-life ecological phases of the white sucker in Jack Lake, Ontario. *Transactions of the American Fisheries Society* 112:308-313.
- Curry, K. D., and A. Spacie. 1984. Differential use of stream habitat by spawning catostomids. *American Midland Naturalist* 11:267-279.
- Dicken, S. N. 1980. Pluvial Lake Modoc, Klamath County, Oregon, and Modoc and Siskiyou counties, California. *Oregon Geology* 42:179-187.
- Gagnon, M. M., D. Bussieres, J. J. Dodson, P. V. Hodson. 1995. White sucker (*Catostomus commersoni*) growth and sexual maturation in pulp mill-contaminated and reference rivers. *Environmental Toxicology and Chemistry* 14: 317-327.
- Geen, G. H., T. G. Northcote, G. F. Hartman, and C. C. Lindsey. 1966. Life histories of two species of catostomid fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. *Journal of the Fisheries Research Board of Canada* 23:1761-1788.
- Gilbert, C. H. 1898. The fishes of the Klamath River Basin. *Bulletin of the U.S. Fish Commission* 17:1-13.
- Golden, M. P. 1969. The Lost River sucker. Oregon Game Commission, Administrative report.
- Goodgame, L. S., and L. E. Miranda. 1993. Early growth and survival of age-0 largemouth bass in relation to parental size and swim-up time. *Transactions of the American Fisheries Society* 122:131-138.
- Hubbard, L. L. 1970. Water budget of Upper Klamath Lake, southwestern Oregon. U.S. Geological Survey Hydrologic Investigations Atlas HA=351, scale 1:250,000.
- Jenkins, R. E. 1970. Systematic studies of the catostomid fish tribe Moxostomatini. Doctoral dissertation, Cornell University, Ithaca, New York.
- Kann, J. 1998. Ecology and water quality dynamics of a shallow hypereutrophic lake dominated by cyanobacteria (*Aphanizomenon flos-aquae*). Doctoral dissertation. University of North Carolina, Chapel Hill.
- Leino, R. L., and J. H. McCormick. 1997. Reproductive characteristics of the ruffe, *Gymnocephalus cernuus*, in the St Louis River estuary on western Lake Superior: A histological examination of the ovaries over one annual cycle. *Canadian Journal of Fisheries and Aquatic Sciences* 54:256-263.
- Miller, R. R., and G. R. Smith. 1981. Distribution and evolution of *Chasmistes* (Pisces: Catostomidae) in western North America. *Occasional Papers of the Museum of Zoology University of Michigan*, Number 696, 46 pages.
- Miller, W. E., and J. C. Tash. 1967. Upper Klamath Lake studies, Oregon. Federal Water Pollution Control Administration, Pacific Northwest Laboratory, Water Pollution Control Series, WP-20-8.
- Moyle, P. B. 1976. Inland fishes of California. University of California Press, Berkeley.

- Nesler, T. P., R. T. Muth, and A. F. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. *American Fisheries Society Symposium* 5:68-79.
- Noga, E. J. 1996. Fish disease: diagnosis and treatment. Mosby-Year Book, Inc. St. Louis, Missouri.
- Perkins, D. L., J. Kann, and G. G. Scoppettone. 2000. The role of poor water quality and fish kills in the decline of endangered Lost River and shortnose suckers in Upper Klamath Lake. U. S. Geological Survey, Report to the Bureau of Reclamation.
- Ridgway, M. S., B. J. Shuter, and E. E. Post. 1991. The relative influence of body size and territorial behavior on nesting asynchrony in male smallmouth bass, *Micropterus dolmieu* (Pisces: Centrarchidae). *Journal of Animal Ecology* 60:665-681.
- Scoppettone, G. G. 1988. Growth and longevity of the cui-ui and longevity of other Catostomids and Cyprinids in western North America. *Transactions of the American Fisheries Society* 117:301-307.
- Scoppettone, G. G., and M. E. Buettner, and P. H. Rissler. 1993. Effect of four fluctuating temperature regimes on cui-ui, *Chasmistes cujus*, survival from egg fertilization to swim-up, and size of larvae produced. *Environmental Biology of Fishes* 38:373-378.
- Scoppettone, G. G., M. Coleman, and G. A. Wedemeyer. 1986. Life history and status of the endangered cui-ui of Pyramid Lake, Nevada. U.S. Fish and Wildlife Service, Fish and Wildlife Research, issue 1.
- Scoppettone, G. G., and G. Vinyard. 1991. Life history and management of four endangered lacustrine suckers. Pages 359-377 in W. L. Minckley and J. E. Deacon, editors. *Battle against extinction - Native fish management in the American West*. The University of Arizona Press, Tucson.
- Scoppettone, G. G., G. A. Wedemeyer, M. Coleman, and H. Burge. 1983. Reproduction by the endangered cui-ui in the lower Truckee River. *Transactions of the American Fisheries Society* 112:788-793.
- Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. *Journal of the Fisheries Research Board of Canada, Bulletin* 184.
- Snyder, D. E. 1983. Fish eggs and larvae. Pages 165-198 in L. A. Nielsen and D. L. Johnson, editors. *Fisheries techniques*. American Fisheries Society, Bethesda, MD.
- Stacey, N. E. 1984. Control of the timing of ovulation by exogenous and endogenous factors. Pages 207-222 in *Fish reproduction: strategies and tactics*. G. W. Potts and R. J. Wootton, editors. Academic Press, New York.
- Sule, M. J., and T. M. Skelly. 1985. The life history of the shorthead redhorse, *Moxostoma macrolepidotum*, in the Kankakee River drainage, Illinois. Illinois Natural History Survey, Biological Notes No. 123.
- Trépanier, S., M. A. Rodríguez, and P. Magnan. 1996. Spawning migrations in landlocked Atlantic salmon: time series modeling of river discharge and water temperature effects. *Journal of Fish Biology* 48:925-936.

Winemiller, K. O., and K. A. Rose. 1992. Patterns of life-history diversification in North American fishes: implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* 49:2196-2218.

APPENDIX A. - Number of Lost River suckers (>450 mm) and shortnose suckers (>250 mm) captured from springs along the east shore of Upper Klamath Lake (includes within-season recaptures). Years in which fewer than 10 fish were captured were not included. When only one species was captured from a spring in a given year, the corresponding column for the other species was not presented.

Capture period	Lost River suckers																		Shortnose suckers											
	Sucker Spring										Silver Building Spring					Ouxy Spring			Sucker Spring					Silver Building Sp.		Ouxy Spring				
	1987	1988	1989	1990	1991	1993	1994	1996	1997	1998	1993	1995	1996	1997	1998	1993	1995	1998	1993	1995	1996	1997	1998	1993	1996	1993	1995	1996		
2/25 - 3/3	---	10	---	---	---	---	---	25	4	---	---	---	---	---	---	---	---	---	---	---	---	0	3	---	---	---	---	---	---	
3/4 - 3/10	---	38	---	---	---	---	---	46	---	---	---	---	1	---	---	---	---	---	---	---	---	0	---	---	---	0	---	---	---	
3/11 - 3/17	---	103	---	29	5	---	---	54	17	9	---	13	---	---	---	---	---	---	---	---	---	0	0	0	---	---	---	---	---	
3/18 - 3/24	---	17	---	---	11	31	---	25	---	35	1	---	---	---	---	---	---	---	---	---	0	---	0	---	0	---	---	---	---	
3/25 - 3/31	119	15	131	23	---	102	---	1	---	2	11	---	6	---	7	---	---	---	---	---	0	---	16	---	0	0	8	---	---	2
4/1 - 4/7	10	---	42	---	---	---	---	---	---	1	---	---	---	---	---	---	---	2	---	---	---	---	0	---	---	---	---	---	---	
4/8 - 4/14	24	---	---	---	---	---	6	---	---	11	---	---	---	---	---	---	---	---	---	---	---	---	0	---	---	---	---	---	---	
4/15 - 4/21	18	---	---	---	---	---	---	---	13	58	---	---	---	---	---	---	---	---	---	---	---	1	---	10	6	---	---	---	---	
4/22 - 4/28	---	---	---	---	---	16	---	---	---	---	---	---	---	---	---	---	4	---	---	---	4	---	---	---	---	---	---	10	---	
4/29 - 5/5	---	---	---	---	---	---	---	---	---	---	14	---	---	---	---	0	---	---	---	---	---	---	---	---	---	11	---	5	---	
5/6 - 5/12	---	---	---	---	---	12	---	---	4	20	0	---	---	1	---	28	---	---	---	---	14	---	---	0	1	1	---	26	---	
5/13 - 5/19	---	---	---	---	---	1	---	---	---	32	4	---	---	---	---	---	---	---	---	---	0	---	---	---	0	3	---	---	---	
5/20 - 5/26	---	---	---	---	---	---	---	---	---	---	1	---	---	---	---	1	---	3	---	---	---	---	---	---	2	---	1	---	---	

APPENDIX B. - Fecundity of Lost River and shortnose suckers captured in spring 1987 and 1988. Suckers were from the Williamson and Sprague rivers unless noted otherwise. Fecundity was estimated gravimetrically or volumetrically (the latter indicated with italics).

Fork length (mm)	Mean no. eggs (per g or <i>ml</i> )	SD	Gonad (g or <i>ml</i> )	Total no. eggs
Shortnose suckers				
451 <sup>1</sup>	177.5	6.91	218.3	38,744
408 <sup>1</sup>	198.1	15.27	158.4	31,375
377	211.9	11.79	153.8	32,580
439	170.5	13.39	223.9	38,169
393	139.2	35.94	283.2	39,413
395	204.2	26.74	224.6	45,864
439	<i>136.8</i>	<i>11.44</i>	<i>185.0</i>	<i>25,308</i>
362	<i>172.9</i>	<i>18.78</i>	<i>104.0</i>	<i>17,982</i>
458 <sup>1</sup>	<i>143.9</i>	<i>12.25</i>	<i>317.0</i>	<i>45,612</i>
445 <sup>1</sup>	<i>169.3</i>	<i>21.91</i>	<i>176.0</i>	<i>29,790</i>
351 <sup>3</sup>	---	---	---	34,114
367 <sup>3</sup>	---	---	---	37,790
380 <sup>3</sup>	---	---	---	34,994
412 <sup>3</sup>	---	---	---	47,470
465 <sup>3</sup>	---	---	---	72,467
426 <sup>5</sup>	238.1	---	171.4	40,810
472 <sup>5</sup>	208.9	---	217.8	45,498
480 <sup>5</sup>	214.5	---	262.2	56,242
436 <sup>5</sup>	182.4	---	218.2	39,800
485 <sup>5</sup>	205.2	---	280.0	57,456
490 <sup>1,6</sup>	---	---	---	36,763
490 <sup>1,6</sup>	---	---	---	56,217
Lost River suckers				
747 <sup>2</sup>	202.1	16.73	482.6	97,556
524	145.4	13.87	419.7	61,015
541	307.1	23.19	318.5	97,803
696	276.0	10.98	789.9	217,990
581	212.3	12.30	333.4	70,797
518	194.3	96.24	227.3	44,164
745	216.4	27.55	492.0	106,457
473 <sup>3</sup>	---	---	---	235,667
530 <sup>3</sup>	---	---	---	101,886
635 <sup>3</sup>	---	---	---	230,970
647 <sup>3</sup>	---	---	---	185,593
749 <sup>4</sup>	279.4	---	616.5	172,250
737 <sup>4</sup>	286.2	---	782.0	223,808
749 <sup>4</sup>	254.2	---	587.4	149,317
744 <sup>4</sup>	237.2	---	987.0	234,116

<sup>1</sup>Fish collected from Copco Reservoir

<sup>2</sup>Fish collected from Sucker Spring, Upper Klamath Lake

<sup>3</sup>Data from Andreason (1975)

<sup>4</sup>Data from Golden (1969)

<sup>5</sup>Data from Mills (1980); standard lengths were increased by 30 mm to approximate fork lengths

<sup>6</sup>Data from Coots (1965)